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TITLE NONRADIAL PULSATIONS OF DELTA SCUTI STARS

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NONRADIAL PULSATIONS OF δ SCUTI STARS

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I. INTRODUCTION

Delta Scuti variables are known to pulsate in nonradial as well as radial modes of oscillation. Theoretical models using the linear, nonadiabatic, nonradial approximations have still not been able to convincingly match the periods and mode excitation of real stars. Calculations typically come up with a number of unstable modes with a variety of periods. For the most part they do not match the observed nonradial periods. What is the problem? What we would like to emphasize in this paper is that in order to analyze a stellar model for nonradial stability it is necessary to have a good evolution model to start with. Calculations by Fitch (1981) and Clancy and Cox (1982) suffered from this problem. They tried to match δ Scuti itself and noted that the behavior of the eigenvectors in the deep interior made interpretation of the theoretical results difficult and that at that time it did not seem possible to match the periods of δ Scuti.

We had hoped that it would be possible to start with a complete stellar model obtained through evolution calculations and to vary the stellar parameters such as luminosity, mass and radius by small amounts and still have a satisfactory model for our envelope code. Even though we can construct a model which has its interior boundary very near the center it is still an inward integration for which the solutions tend to diverge as the center of the star is approached. We found that this does not work and that we must use a complete model.

II. MODEL

The preliminary model discussed here should be referred to as δ Scuti "like" since the only detailed evolution model available at the time was slightly too luminous and too cool to be in the observed instability strip (cf. Fitch, 1981). The model we used was kindly provided by S. Becker (1986). It is useful to present the results for this model since it should tell us whether or not we are able to obtain meaningful eigenvectors for the nonradial modes in the deep interior of the star. Table 1 gives some of the details about the model.

In table 1 q is the mass fraction interior to a given point in the star. The Iben fit to opacities and equation of state data is used in the deep interior so that our model will track that of Becker. Near the surface we used the Stellingwerf fit since it provides better detail in the hydrogen and helium ionization zones. The evolution models typically do not go to temperatures lower than about 100,000K. The mass contained in the inner, inert ball is approximately equal to that of the shell next to it.

III. STABILITY ANALYSIS

Even though our model is slightly cooler than observed variable stars in this region of the H-R diagram we still expect to obtain modes that are unstable since, as is well known unless a proper treatment of convection is included the red edge is not found with our pulsation models. In Table 2 we present an analysis of our model for the first three radial modes and $l = 2$, g modes. We see in table 2 that as in previous work the radial modes tend to be more unstable as we go to higher order modes. The periods here are about a factor of two times those for δ Scuti. This is to be expected with our larger mass and radius. The g modes indicated are all unstable. Higher order modes, as well as those of lower order than g_8 are found to be stable. For modes near the stable-unstable boundary region growth rates tend to be somewhat unreliable. The reason for the band of unstable modes is that at low order the eigenvector samples the hydrogen and first helium ionization driving but not the second helium driving. Higher order modes are more unstable since the second helium ionization driving region is sampled. At the very highest order modes, above about g_{16} you sample the most radiation damping at $T > 70,000$K and damping in the μ gradient region near the center. Figure 1 is a plot of the radial eigenvector for the g_8 mode. It does appear that we have made a marked improvement over previous calculations. The nodes near the center are well defined and do not exhibit the noise evident in the work of Clancy and Cox. The work plot shown in Figure 2 is of interest. We see that the driving is coming from the outer ionization of hydrogen and helium. The double outer peak is primarily an equation of state(Γ) effect due to the ionization of hydrogen and first ionization of helium. The details of the driving and damping are of course a complicated interaction of the kappa and gamma effects.

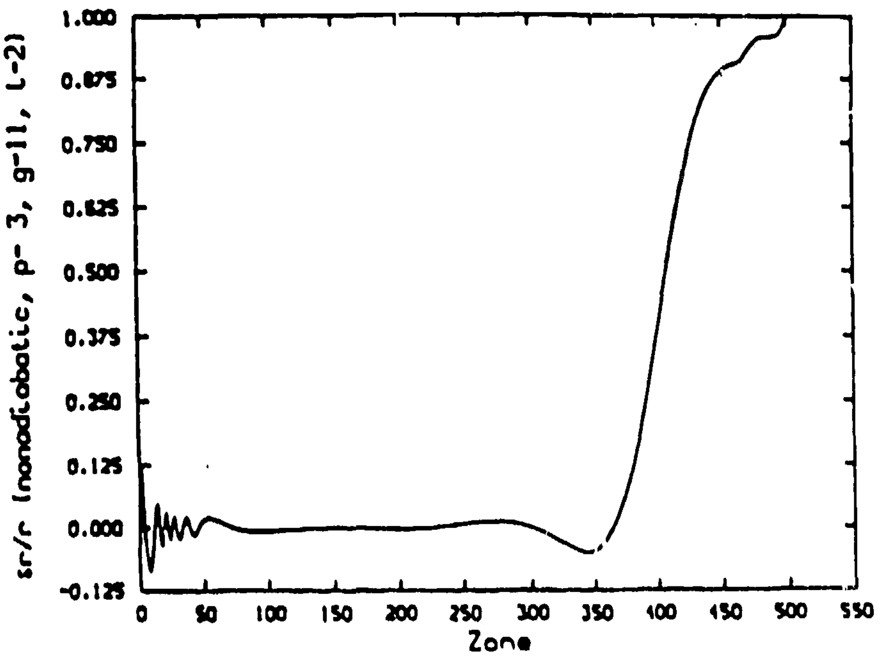

Figure 1. $\delta r/r$ vs zone number for the g_8 nonradial mode.

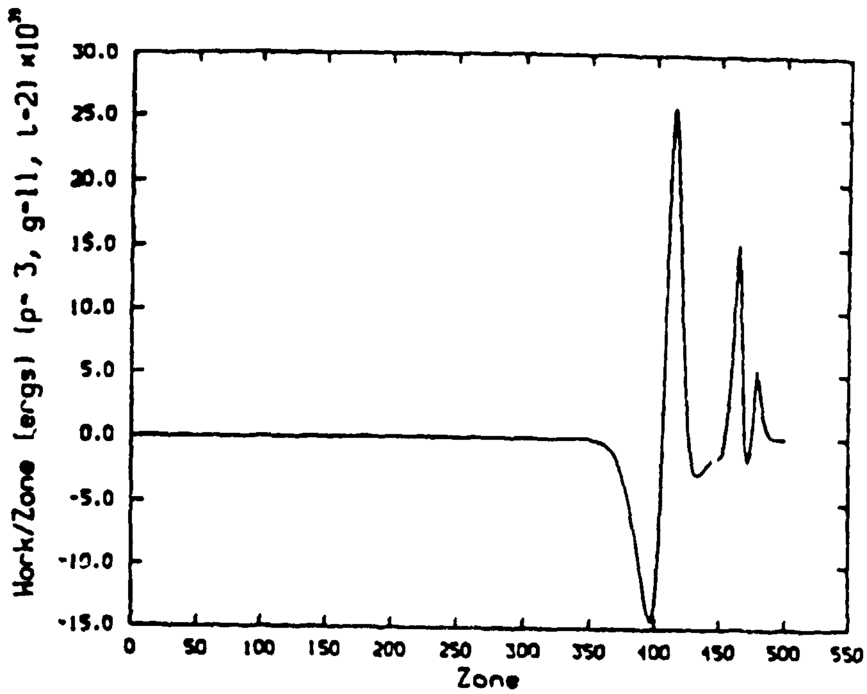

Figure 2. Work/zone vs. zone number for the g_8 nonradial mode.

IV. SUMMARY AND CONCLUSIONS

We have used an improved stellar evolution model, with its detailed composition structure to look at the nonradial behavior of a star near the region in the H-R diagram where the δ Scuti variables are found. We are able to obtain satisfactory solutions to the linear nonadiabatic equations and intend to use newly calculated evolution models to further study the pulsational stability of this class of variable stars. Lee (1985) has recently calculated δ Scuti models for l=0,1,2 and 3 modes. He finds a large number of unstable modes. With all the work done to date, there still appears to be a conflict between the number of calculated unstable modes and those observed.

TABLE 1

δ Scuti "like" Model

$M = 3M_\odot$, $L = 64.6L_\odot$, $T_{eff} = 6166K$

Composition Structure

Surface to $q = 0.57$	$X = 0.69$, $Z = 0.03$
$q = 0.57$ to 0.15	$X = 0.69$ to 0.67
$q = 0.15$ to 0.09	$X = 0.67$ to 0.27
$q = 0.09$ to 0.07	$X = 0.27$ to 0.00
$q = 0.07$ to 0.00	$X = 0.00$

Material Properties

Stellingwerf fit from surface to $T = 300,000$K
Iben fit from $T = 300,000$K to center

Table 1 continued

Convection

Mixing length with $l/H_p = 1.0$

Central Ball Surface

$M = 2.85 \times 10^{-3} M_*$
$L = 8.17 \times 10^{-3} L_*$
$T = 4.5 \times 10^{7}$K
$R = 1.2 \times 10^{-3} R_*$

TABLE 2

Radial Modes

Mode	Period(days)	Period(hrs)	η	Q(days)
F	0.3765	9.036	4.3×10^{-5}	0.0347
1H	0.2862	6.869	4.1×10^{-4}	0.0264
2H	0.2271	5.450	1.7×10^{-3}	0.0209

Nonradial Modes ($l = 2$)

Mode	Period(days)	Period(hrs)	η
g_{15}	0.397	9.53	3.8×10^{-6}
g_{14}	0.349	8.38	1.7×10^{-5}
g_{13}	0.309	7.42	1.1×10^{-5}
g_{12}	0.279	6.70	1.2×10^{-4}
g_{11}	0.242	5.81	6.6×10^{-4}
g_{10}	0.221	5.30	5.3×10^{-4}
g_9	0.195	4.68	2.2×10^{-3}
g_8	0.173	4.15	1.6×10^{-3}

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